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for

METHOD AND SYSTEM FOR GOLF SWING ANALYSIS AND TRAINING

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METHOD AND SYSTEM FOR GOLF SWING ANALYSIS AND TRAINING

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001] This patent application claims the benefit of U.S. Provisional Patent Application No. 60/501,044, entitled, "Method and System for Golf Stroke Analysis and Training," and filed September 8, 2003.

FIELD

[0002] This disclosure pertains generally to a sport training system and, more particularly, to an intelligent sports club, bat or racket that takes quantitative measurements of a swing for real-time feedback and subsequent analysis and display.

BACKGROUND

[0003] Various inventions are described to assist golfers' efforts to improve their swing. One category of devices involves systems of restraints on the golfer's body or on the club to force the golfer into a more perfect swing. Restraint based systems operate on the premise that by forcing a golfer into a given stance or swing pattern, the golfer will inculcate the lesson as a form of muscle memory that can then be employed while golfing with a standard club. However, a golfer's natural tendency is to resist the restraint system and thereby learn a stance or swing pattern predicated on the

presence of the restraint system. In the absence of the restraint system, the user's new stance or swing pattern is incorrect.

[0004] Other devices attempt to mechanically react to the swing with hinged clubs or moving weights. Mechanically reactive systems provide hinged or weighted systems that react to various qualities of a swing. For example, a hinged golf club is specified that stays rigid during the course of a good swing, but will collapse under the conditions of a poor club swing. These devices do not allow the golfer to train with a physically intact, standard golf club. Also, some of these devices do not allow for actually striking a golf ball during the swing. Once again, the golfer is learning swing habits divorced from requirements of swinging a standard golf club in a standard manner.

[0005] Another category of devices is electronic in nature and entirely external to the golf club, typically involving some type of swing motion capture. These systems typically employ arrays of sensors and cameras configured around the golfer. Visualization and analysis of individual frames, as well as slow motion animation of the golf swing are difficult with conventional video analysis because of the required high frame rates. Further, high frame rates require large amounts of data storage and processing power. In some instances, the users must also affix indicators or sensors on their person and/or their club. The inconvenience and complexity of these externally configured systems prevent this technology category from gaining widespread appeal in the golfing community. In

addition, because of the nature of these systems, golfers are not able to play a round of golf while using these systems.

[0006] A class of electronic devices exists that requires users to mount the devices on the outside of the shaft of the club. The weight of these devices changes the club's swing characteristics and renders swing lessons less meaningful. The externally mounted devices significantly change the look of the club and may loosen or move on the shaft.

[0007] Another class of electronic devices exists that require users to mount devices on their person. For example, in U.S. Pat. No. 6,048,324, issued to Socci et al., the specification discloses headgear for detecting head motion and providing an indication of head movement. An object of this invention is to provide players with a device to teach proper ball striking in a variety of sports including golf by tracking head motion. Devices designed to exclusively monitor a subset of the golfer's motions do not adequately capture the various motions required for a human to hit a golf ball. Therefore, these devices cannot precisely predict the path of the golf club during a swing.

[0008] Lastly, in U.S. Pat. No. 6,648,769, issued to Lee et al., a device is disclosed to capture and analyze data related to a golf club swing. This device is comprised of electronic components in the distal end of the club shaft with additional circuitry in the head of the club. The presence of components in the modified golf club head degrades the users' experience by providing a different tone at ball strike. Furthermore, by locating critical components in the club head, the region of the club which experiences the highest rates of

acceleration, the device is more susceptible to mechanical degradation and failure. The club requires a wired link to download swing data to a computing device. This wired link is cumbersome for users. Finally, the club provides feedback to the user regarding their swing only after data is downloaded to a computing device. This lack of real-time feedback, during the course of the swing, provides a less meaningful learning experience to the user.

BRIEF DESCRIPTION OF THE FIGURES

[0009] For a more complete understanding of the present disclosure, and the advantages thereof, reference is now made to the following brief descriptions taken in conjunction with the accompanying drawings, in which like reference numerals indicate like features.

[0010] **FIGURE 1** shows an instrumented golf club (IGC), which is a component of the claimed subject matter;

[0011] **FIGURE 2** shows additional components of the claimed subject matter, i.e. a radio frequency (RF) link box, a universal serial bus cable and a computing device executing a software program;

[0012] **FIGURE 3** shows a battery recharger designed to be used with the IGC of **FIGURE 1**;

[0013] **FIGURE 4** shows two views of a club grip incorporated into the IGC, i.e., an outer view and an expanded inner view;

[0014] **FIGURE 5** shows an exploded view of the top portion of the IGC grip;

[0015] **FIGURE 6** shows three views of an Inertial Measurement Unit (IMU) incorporating the claimed subject matter;

[0016] **FIGURE 7** shows a three-dimensional frame of reference corresponding to the IGC with respect to a three-dimensional frame of reference corresponding to the world;

[0017] **FIGURE 8** shows an exploded view of the RF link box introduced in **FIGURE 2**;

[0018] **FIGURE 9** shows an exemplary swing path data model used to store information collected by the IGC;

[0019] **FIGURE 10** shows an exemplary analysis application 88 graphical user interface (GUI) that provides a user access to the functionality and configuration of the IGC;

[0020] **FIGURE 11** shows an alternative embodiment of the RF link box of **FIGURES 1** and **8**;

[0021] **FIGURE 12** is a flowchart of a Data Collection process associated with the IGC and the System of Golf Swing Analysis and Training (SGSAT);

[0022] **FIGURE 13** is a flowchart of the Process Link Box step of the Data Collection process of **FIGURE 12** in more detail;

[0023] **FIGURE 14** is a flowchart of the Process Swing step of the Data Collection process of **FIGURE 12** in more detail; and

[0024] **FIGURE 15** is a flowchart of a Data Display process associated with the IGC and the SGSAT.

DETAILED DESCRIPTION OF THE FIGURES

[0025] Although described with particular reference to a golf club and more specifically to a driver, the claimed subject matter can be implemented in many types of devices. With reference to other golf clubs the claimed subject matter is applicable to all types of golf clubs, including irons, fairway woods, wedges, and putters. Another type of sports device that may benefit from the claimed subject matter is a racket. All racket sports include tennis, racquetball, squash and badminton. With minor software modifications to the disclosed embodiment, the advantages of real-time swing feedback, swing data storage, transmission, and advanced analysis can be extended to the players of racket sports. Further, additional embodiments may include bats such as those used in baseball, softball, t-ball, cricket, polo, etc. With minor software modifications to the disclosed embodiment, the advantages of real-time swing feedback, swing data storage, transmission, and advanced analysis could be extended to the players of bat sports.

[0026] An additional embodiment may be adapted for use with a video game controller or computer game controller. Real time data transmission from an instrumented game controller allows for real-life swing data to be directly fed into any sports video or computer game. In addition, the portions of the disclosed invention can be implemented in software, hardware, or a combination of software and hardware. The hardware portion can be implemented using specialized

logic; the software portion can be stored in a memory and executed by a suitable instruction execution system such as a microprocessor, tablet personal computer (PC), or desktop PC.

[0027] Several exemplary objects and advantages of the claimed subject matter, described for the sake of simplicity only with respect to a golf club, are as follows:

- Provide a system for capturing, recording, and analyzing data pertaining to a golf club swing that resides entirely within the distal end (grip end) of the instrumented golf club;
- Provide a system for capturing, recording and analyzing data pertaining to a golf club swing without noticeably modifying the instrumented club's swing characteristics as compared to the characteristics of a standard, non-instrumented golf club;
- Provide a system for capturing, recording and analyzing data pertaining to a golf club swing without modifying the appearance or character of the head of the instrumented golf club or the shaft of the instrumented golf club as compared to a standard, non-instrumented golf club;
- Provide a system for capturing, recording and analyzing data pertaining to a golf club swing such that the instrumented golf club can be used to strike a standard golf ball in both playing and practice conditions thereby avoiding swing

idiosyncrasies which may occur when golfers swing in the absence of a golf ball;

- Provide a system for users to improve their golf swing without imposing outside physical restraints or tethers on a golfer and thereby avoiding the creation of artificial swing habits that compensate for the outside restraints;
- Provide a system which generates audible real-time feedback during the course of a swing thereby allowing a user to immediately recognize and address poor swing habits;
- Provide a system which does not require the placement or utilization of devices affixed to the exterior of a golf club for capturing, recording, and analyzing data pertaining to a golf club swing;
- Provide a system which requires minimal amounts of memory storage and processing power to allow visualization and analysis of individual frames as well as slow motion animation of the golf swing;
- Provide a system which does not require the placement or utilization of devices affixed to the golfer's body while capturing, recording, and analyzing data pertaining to a golf club swing;
- Provide a system which does not require the placement or utilization of devices positioned

around the golfer while capturing, recording, and analyzing data pertaining to a golf club swing;

- Provide a system for capturing, recording and analyzing data pertaining to a golf club swing which allows for subsequent wireless transfer of single or multiple swing data sets to an application resident on a computing device for further swing analysis; and
- Provide a system for capturing, recording and analyzing data pertaining to a golf club swing which includes highly accurate club linear acceleration data along 3 orthogonal axes and highly accurate club angular rate data around said axes and algorithms sufficient to convert said data into highly accurate club positioning data.

Additional exemplary objects and advantages are as follows:

- Provide a system which allows for extensive, subsequent swing analysis on a computing device;
- Provide a system packaged in a sufficiently generic way that multiple, disparate clubs may be instrumented and therefore enabled for swing data analysis;
- Provide a system with an active but dozing mode that increases battery life and reduces the incidence of non-swing motion recording; and

- Provide a system that allows for the transmission of swing data from the golfer to a second, remote party for second-party analysis.

[0028] Other aspects, objectives and advantages of the claimed subject matter will become more apparent from the remainder of the detailed description when taken in conjunction with the accompanying figures.

[0029] **FIGURE 1** shows an instrumented golf club (IGC) **18**, which is one component of a System of Golf Swing Analysis and Training (SGSAT) of the claimed subject matter. Other components of SGSAT include a radio frequency (RF) link box **38** (see **FIGURE 2**) coupled to a computing device **48** (see **FIGURE 2**) and a battery recharger **22** (**FIGURE 3**).

[0030] IGC **18** includes a head **34** and a shaft **34**, both of which are similar to shafts and heads on a typical golf club. Although illustrated as a driver, head **34** can be any type of golf club, including but not limited to, an iron, a wedge, a wood and a putter. As mentioned above, the claimed subject matter is not limited to golf clubs but can be applied to many types of bats, rackets and game controllers.

[0031] Attached to the top of shaft **34** is a grip **30**, into which the claimed subject matter is incorporated. Grip **30** includes a Power On/Mute/Power Off button **20**, a battery recharge connector **28**, a battery recharge connector cover **22**, a grip faceplate **24** and a Flag Swing button **26**.

[0032] Power On/Mute/Power Off button **20** is pushed once to power on the IGC **18**. Once the IGC **18** is powered on, button **20** is pushed to toggle on and off an audio feedback signal that

indicates to a user when a particular swing has broken a plane representing a correct swing. To power off the IGC 18, button 20 is pushed in and held for four or more seconds.

[0033] Battery recharge connector 28 is a socket into which battery recharger 22 is inserted to charge a battery pack 68 (see **FIGURE 6**) within IGC 18. Battery recharge connector cover 22 is a plastic cover that has two protruding posts, one of which plugs into connector's 28 socket and keeps moisture and dirt from entering socket 28 when battery recharger 22 is not connected to IGC 18. When IGC 18 requires recharge, cover 22 is lifted and rotated around the second protruding post to expose connector 28 and battery recharger 22 is inserted into connector 28. Grip faceplate 24 is a finishing piece for an Inertial Measurement Unit (IMU) 53 (see **FIGS. 4 and 6**) that fits within grip 30. Finally, a flag swing button 26 is pushed when a user desires to mark the data corresponding to a particular swing of IGC 18 for future investigation using an analysis application 88 (see **FIGURE 10**) on a computing device 48 (see **FIGURE 2**). A saved swing can also become a benchmark, or reference swing, against which subsequent swings can be compared, including setting a reference for the breaking planes sounds.

[0034] **FIGURE 2** shows additional components of SGSAT of the claimed subject matter, i.e. Radio Frequency (RF) Link Box 38, a universal serial bus (USB) cable 46 and a computing device 48 that hosts two software applications, one for processing swing data (see **FIGURE 14**) and one for interfacing with IGC 18 (see **FIGURE 13**). USB cable 46 communicatively couples computing system 48 and RF Link Box 38 via a USB

connector **44**. USB cable **46** is used as an example only. One with skill in the computing arts would recognize there are many ways, both wired and wireless, to connect computing system **48** and RF Link Box **38**.

[0035] A Power/USB connection light emitting diode (LED) **42** provides indication of whether or not RF link box **38** is connected to power and computing system **48**. A club detection data transfer LED **40** provides indication of whether or not RF link box **38** is in communication with IGC **18** by lighting up and provides indication of whether data is being transferred between IGC **18** and RF link box **38** by blinking. RF link box **38** is described in more detail below in conjunction with **FIGURE 8**.

[0036] **FIGURE 3** shows a battery recharger **22** designed to be used with the IGC **18** of **FIGURE 1**. Recharger **22** plugs into IGC **18** at battery recharge connector **28** (**FIGURE 1**) and functions to recharge battery pack **68** (see **FIGURE 6**). Recharger **22** includes a plug for connecting recharger **22** to a standard AC power outlet and a transformer to convert AC current into DC current. Recharger **22** is similar to rechargers typically provided in conjunction with cordless appliances, wireless telephones, and many other common household devices.

[0037] **FIGURE 4** shows club grip **30** and an expanded view of a top portion of IMU **53**, which fits within IGC **18**. Battery recharge connector cover **22**, grip faceplate **24**, power on/mute/power off button **20** and flag swing button **26** were introduced above in conjunction with **FIGURE 1**. As explained above, a protruding post on battery recharge connector cover

22 fits into grip faceplate 24 to protect battery recharge connector 28. In addition, grip faceplate 24 has a cover anchor hole 23, into which a second post on cover 22 is inserted. When inserted into hole 23, friction and compression between the second protruding post and faceplate 24 secure cover 22 against faceplate 24.

[0038] Below grip faceplate 24 is an antenna board 50 that is employed in wireless communication between IGC 18 and RF link box 38 (FIGURE 2). Antenna board 50 is coupled to a main circuit board 52, which is explained in more detail below in conjunction with FIGURE 6. Illustrated parts 20, 22, 24, 26, 50 and 52 connect together and are coupled to, and part of, IMU 53, which fits into grip 30. A tab 51 extends from main board 52 and serves to secure IMU 53 in a fixed position relative to grip 30. A second, opposing tab (not shown) protrudes from the other side of main board 52 and also serves to secure IMU 53 in position relative to grip 30.

[0039] FIGURE 5 shows a detailed view of the top portion of IGC grip 30. Two slots 55 provide space into which tab 51 (FIGURE 4) and the second opposing tab can be positioned to secure IMU 53 within grip 30.

[0040] FIGURE 6 shows three views of IMU 53 (FIGURE 4), i.e. an outer view 101, an inner, exploded view 103 and an inner, assembled view, or assembly, 105. Outer view 101 shows a tube 54 into which assembly 105 fits. Also shown is a screw 56 which secures assembly 105 to tube 54.

[0041] Exploded view 103 includes antenna board 50 and a full view of main board 52, both of which were introduced above in conjunction with FIGURE 4. Antenna board 50 is

coupled both mechanically and electrically to main board **52**. Also coupled mechanically and electrically to main board **52** are a club transceiver chip **78**, a sounder **76**, an accelgyro board **60** and a z-gyro board **62**. Also included within tube **54** are a battery pack **68**, two tube inserts **58**, a battery standoff **64**, and battery pack wires **66**.

[0042] Club transceiver chip **78**, which in this example is a 2.4 GHz transceiver, is responsible for wireless communication between IGC **18** (**FIGURE 1**) and RF link box **38** (**FIGURE 2**). Transceiver chip **78** employs a quarter wave monopole antenna (not shown) located on antenna board **50**. Sounder **76** provides an audio feedback signal to a user of IGC **18** when a particular swing falls outside of acceptable parameters.

[0043] Screw **56** extends through one wall of tube **54**, through one tube insert **58**, through main board **52**, through second tube insert **58** and through the opposite wall of tube **54**. Screw **56** serves as a main point of structural integrity within IMU **53**. In other words, screw **56** and tube inserts **58** prevent the various components of assembly **105** from vibrating within tube **54**.

[0044] IMU **53** employs three solid-state gyroscopes (not shown), such as Analog Devices' ADXRS300, to measure angular rates around axes C_x , C_y , and C_z (see **FIGURE 7**). A gyroscope located on accel/gyro board **60** measures the angular rate of rotation around C_x , a gyroscope located on main board **52** measures the angular rate of rotation around C_y , and a gyroscope located on the Z-gyro board **62** measures the angular rate of rotation around C_z . These gyroscopes are configured

with a bandwidth of 1500 degrees per second in order to record a typical golf swing, although other bandwidths are possible depending upon the particular application. Additional signal conditioning and analog to digital conversion circuitry (not shown) supports the three gyroscope sensors.

[0045] IMU **53** employs two dual-axis accelerometers (not shown), such as Analog Devices ADXL210e, to measure linear acceleration along axes C_x , C_y , and C_z . An accelerometer on main board **52** measures linear acceleration along C_x and C_z axes. An accelerometer on accel/gyro board **60** measures linear acceleration along C_y axis and duplicated data along the C_z axis. Although one embodiment uses only one channel of the C_z data, another embodiment may compare both channels of C_z data for such benefits as increased accuracy and/or signal noise reduction.

[0046] It should be noted that accelerometers can measure both linear acceleration and forces due to gravity. The ability to measure the effects of gravity allows for the resolution of a gravity vector that in effect tells IGC **18** which direction is down with respect to the surrounding world (see **FIGURE 7**).

[0047] Also included on main board **52** is a temperature sensor (not shown) for providing temperature compensation of data from the gyroscopes and accelerometers because the performance characteristics of the gyroscopes and accelerometers can be affected by temperature. A microprocessor (not shown), on main board **52**, is employed as a central processing unit for IGC **18**. The microprocessor controls the other components of board **52**, collects sensor

data, monitors system temperature, corrects sensor data for temperature related distortion, processes the corrected sensor data into position, velocity, and acceleration vectors, stores the corrected sensor data in flash memory (not shown) for later download, and performs real-time collision detection of IGC 18 with respect to the swing planes, explained below in conjunction with **FIGURE 7**.

[0048] Swing data is stored on 8 MB of serial flash memory (not shown) on main board 52. One embodiment of the claimed subject matter employs approximately 72 kB of memory per recorded swing therefore allowing over 100 swings to be stored on the flash memory before the flash memory is consumed. Another embodiment of the claimed subject matter may use higher quantities of memory that would allow for data captured for a higher number of swings. In addition, other embodiments may sample fewer data points per swing, thereby allowing for data to be captured from a higher number of swings. Furthermore, other embodiments may employ data compression algorithms to allow for more data to be captured from a higher number of swings.

[0049] Finally, battery standoff 64 provides separation between main board 52 and battery pack 68, which provides power for the components of IMU 53. Battery pack 68 is electrically coupled to z-gyro board 62, and therefore the other components of IMU 53, via battery pack wires 66. In this example, battery pack 68 consists of five (5) rechargeable metal hydride cells, although there are many possible configurations. The power supply sub-system, which includes battery pack 68 and a voltage regulator (not shown)

on main board **52**, generates voltage levels as required for device components, e.g. 1.8 V, 3.3 V and 5.0 V supplies.

[0050] **FIGURE 7** shows IGC **18** within two three-dimensional, orthogonal frames of reference, a frame **107** plotted with reference to a typical position for IGC **18** (**FIGURE 1**) and a frame **109** plotted with reference to gravity corresponding to the world. Frame **107** corresponds to a coordinate system in which the positive club X-axis is identified as ' C_x ', the positive club Y-axis is identified as ' C_y ' and the positive club Z-axis is identified as ' C_z '. Frame **109** corresponds to a coordinate system in which the positive world X-axis is identified as ' G_x ', the positive world Y-axis is identified as ' G_y ' and the positive world Z-axis is identified as ' G_z '.

[0051] During processing of data collected by IGC **18** both frames **107** and **109** are applicable. Frame **107** corresponds to a frame of reference for measurements taken by accelgyro board **60** and Z-gyro board **62** (**FIGURE 6**). Frame **109** corresponds to a frame of reference of a user of IGC **18** and a display (not shown) for providing feedback to the user. Those with skill in the mathematical arts can easily convert measurements back and forth between frames **107** and **109**.

[0052] The claimed subject matter builds on the concept of a golfer keeping their swing within a region bounded by a "lower swing plane" and an "upper swing plane" (not shown). The lower swing plane passes roughly from the heel of golf club head **36** (**FIGURE 1**) through the golfer's right hand while the golfer is addressing a golf ball. The upper swing plane passes roughly from the toe of the golf club head **36** through the golfer's right shoulder while the golfer is addressing the

golf ball. Most golfers swinging above the lower swing plane and below the upper swing plane will produce a better swing than those swinging outside of these planes.

[0053] One task of the claimed subject matter is to accurately track the movement of IGC **18** through space over the duration of a swing of IGC **18**, and to produce an audible alert if IGC **18** violates the lower or the upper swing plane. To accomplish this task, the IGC **18** uses inertial measurement unit **53** (**FIGs. 4** and **6**) with data sampling fast enough to capture the dynamics of a golf club swing.

[0054] IMU **53** can also be termed a six degrees of freedom inertial measurement unit since it measures linear acceleration along axes Cx, Cy, and Cz (the first 3 degrees of freedom) and it measures angular rate (rotation speed) around axes Cx, Cy, and Cz (an additional 3 degrees of freedom): Using algorithms known to those well versed in the art of IMUs, the data from these six degrees of freedom yield the orientation and position of IMU **18** as a function of time relative to its initial position. Employing additional algorithms common to this field, the orientation and position of all elements of IGC **18** can be calculated given the orientation and position of the inertial measurement unit **53**. Finally with some basic knowledge of a golfer's physical dimensions and common stance, IGC **18** determines whether or not a swing has remained within the region defined by the upper and lower swing planes.

[0055] **FIGURE 8** shows an exploded view of RF link box **38** first introduced in **FIGURE 2**. A link board **70** is a printed circuit board with the primary function of facilitating

communication between IGC **18** (**FIGs. 1** and **7**) and a software application executed on computing device **48** (**FIGURE 2**). Board **70** incorporates a link board transceiver chip **80**, which is antenna and transceiver circuitry sufficient to enable RF communication between RF link box **38** and transceiver chip **78** (**FIGURE 6**) on main board **52** (**FIGURE 6**) IGC **18**. In this example transceiver chip **80** is a 2.4 GHz transceiver that sends and receives signals on a quarter wave monopole antenna (not shown) on link board **70**.

[0056] The USB circuitry enables communication with computing device **48** via USB connector **44** and USB cable **46** (**FIG 2**). Computing device **48** hosts a software application dedicated to interfacing with IGC **18**. Link board **70** is enclosed in a link box cap **72** and a link box base **74**. Also illustrated are power/USB connection LED **42** and club detection data transfer LED **40**, first introduced in **FIGURE 2**.

[0057] **FIGURE 9** shows an exemplary Swing Path data model **82** used to store information collected by IGC **18** (**FIGs. 1** and **7**) and processed by computing system **48** (**FIGURE 2**). Swing path data **82** includes a swing info header **84**, which stores data related to a particular swing of IGC **18**, and multiple swing data elements **86**. Each swing data element **86** stores measurement information from sensors on main board **52** (**FIGURE 6**) accelgyro board **60** (**FIGURE 6**) and Z-gyro board **62** (**FIGURE 6**) for a particular moment in time of a particular swing corresponding to swing data header **84**. If SGSAT employs a sampling rate of 2k Hertz, then there are 2,000 instances of swing data element **86** generated for each second that a particular swing takes, e.g. if a swing takes 2 seconds, there

are 4,000 instances of swing data element **86** generated for that particular swing.

[0058] Swing info header **84** includes a swing info identifier (ID), which uniquely identifies a particular swing, a club ID, which identifies a particular club used for the swing, a swing start timestamp, which stores a start time for the swing, a swing duration data element, which stores data on how long the swing took from beginning to end, a swing flagged data element, which indicates whether or not the user has indicated that the corresponding swing is of special interest for later use and analysis, and a temperature data element, which stores the ambient temperature from a temperature sensor on main board **52** (**FIGURE 6**) for use in analyzing output from the accelerometers and gyroscopes (**FIG 6**). The user sets the Swing Flagged data element by pushing flag swing button **26** (**FIGURE 4**), typically following a particularly good swing.

[0059] Each swing data element **86** includes a swing info ID, which enables a particular swing data element **86** to be associated with a particular swing info header **84**, a sequence number, which indicates an ordering of multiple swing data elements **84** associated with a particular swing info header **86**, and various data elements corresponding to measurements taken from main board **52**, accelgyro board **60** and Z-gyro board **62**.

[0060] An X-axis accelerometer data element corresponds to a measurement of movement in the C_x axis (**FIGURE 7**) of IGC **18** taken from an accelerometer on accelgyro board **60**. A Y-axis accelerometer data element corresponds to a measurement of movement in the C_y axis (**FIGURE 7**) of IGC **18** taken from the same accelerometer on accelgyro board **60** that measures the C_x .

A Z-axis accelerometer data element corresponds to a measurement of movement in the C_z axis (**FIGURE 7**) of IGC **18** taken from the second accelerometer on main board **52**.

[0061] An X-axis gyroscope data element corresponds to a measurement of angular rotation around the C_x axis of IGC **18** taken by the gyroscope located on accel/gyro board **60**. A Y-axis gyroscope data element corresponds to a measurement of angular rotation around the C_y axis of IGC **18** taken by the gyroscope located on main board **52**. A Z-axis gyroscope data element corresponds to a measurement of angular rotation around the C_z axis of IGC **18** taken by the gyroscope located on Z-gyro board **62**.

[0062] Swing path data model **82** illustrates one particular format for storing data generated by IGC **18**. Those with skill in the computing arts should appreciate that there are other ways to store the data as well as other data, and corresponding data structures, employed by IGC **18** and SGSAT. For example, computing system **48**, or in an alternative embodiment IGC **18**, converts linear acceleration and angular rate measurements into orientation and position information, which also require particular data structures.

[0063] **FIGURE 10** shows an outline for exemplary graphical user interface (GUI), or "analysis application," **88** that provides a user an interface to IGC **18** and SGSAT. One with skill in the programming arts should easily understand how to program analysis application **88**. A flowchart **113** for analysis application **88** is described below in conjunction with **FIGURE 13**.

[0064] Analysis application **88** offers extensive golf swing related analytics using swing path data **82** (**FIGURE 10**), which is collected from IGC **18** (**FIGs. 1** and **4**) by a data collection process **200**, described in detail below in conjunction with **FIGURE 12**, stored on computing device **48** (**FIG 3**), and processed by a data display process **250**, described in more detail below in conjunction with **FIGURE 13**. In an alternative embodiment, analysis application **88** employs orientation and position data, derived from swing path data **82**.

[0065] Specific swing path data **82** records are displayed in a swing record panel **90**. Swing record panel **90** also displays previously downloaded swing path data **82** records. Records **82** displayed in swing record panel **90** can be constrained and filtered using functionality located in a swing record filter panel **92**. Swing record filter panel **92** enables a user of GUI **88** to limit displayed records by time stamp and other characteristics. Swing path data **82** records are selected by the user in swing record panel **90** and then loaded by the analysis application **88** into other constituent panels of analysis application **88**.

[0066] Once a swing path data **82** record has been selected by the user, the user can view an animated reconstruction of the swing in swing viewing panels **94**, **96**, and **98**. Analysis application **88** enables visualization and analysis of individual frames of the swing, of slow motion and real-time animation of the golf swing, and of pre-set key points of the swing such as at address, the top of the swing, ball impact, etc. Animation controls are located in a swing replay control panel **102**. Pre-set key points of the golf swing are accessed

through a swing key point control panel **104**. The animated swing can be viewed from multiple, different simultaneous perspectives in panels **94**, **96**, and **98**, for example front, side, and top-down.

[0067] The Analysis application **88** uses Inverse Kinematics to animate a human figure and give context to the golf swing visualization. A specific algorithm commonly referred to as Cyclic Coordinate Descent is used to allow the position and orientation of swing path data **82** records to drive the state of a simplified human skeleton viewable in swing viewing panels **94**, **96**, and **98**. Another tool provided by analysis application **88** is the display of upper and lower swing planes during swing visualization.

[0068] Analysis application **88** provides the ability to compare a golfer's swing to a reference swing. This reference swing can be derived from several sources. For example, analysis application **88** can create an ideal reference swing based on a user's physical characteristics, a previously recorded swing from another golfer, such as a touring professional golfer, or the user can designate one of their best personal swings as the reference swing. The overlaying of a swing with a reference swing during replay and visualization provides additional analysis context and allows the golfer to analyze their swing for flaws and strengths.

[0069] Beyond visual analysis, analysis application **88** offers extensive primary analytics derived from a swing path data **82** record. These analytics are mainly presented in tabbed windows within the swing analytics panel **106** and within

context sensitive analytics panel **100**. Analytics include, but are not limited to, the following examples:

- Shaft **34** (**FIGURE 1**) Angle at Key Points in the Swing
- Address Line-The position of the club shaft **34** at address, which is perpendicular to the target line
- Club **18** (**FIGURE 1** and **4**) Face Position at Key Points in the Swing
- Club Head **36** (**FIGURE 1**) / Hands Position at Key Points in Swing
- Club Head **36** Speed and Acceleration
- Arc Inscribed by Hands and Club Head **36**
- Angles of Backswing planes, Transition planes, and Downswing planes
- Angle of Attack on the Ball (the club head **36** angle prior to ball impact)
- Estimated Ball Flight Distance
- Time of Pause at Top of Swing
- Club head **36** Drop at Beginning of Downswing
- Estimated Wrist Angle / Cock Angle at Top of Swing
- Maximum rate of Acceleration on Downswing / Rate of acceleration at impact
- Point in downswing of highest velocity
- Lag Distance (distance the butt of club **18** is from the address line when club **18** is parallel to the earth on a downswing.)
- Lag Angle (angle at which club **18** is, relative to the address line, when the butt of club **18** is some

preset distance from the address line on a downswing.)

- Coil Angle (measurement of the rotation of club **18** at its furthest point from address during backswing)
- Estimated Launch Angle of the Ball
- Type of Spin Imparted to the Ball
- Escape Velocity of the Ball
- Angle of incidence (club head **36** path at impact versus target line at address)
- Impact Point on the club **18** face.

[0070] Additional analytics that combine information from multiple, primary analytics are available in analysis application **88**. Examples of composite analytics include, but are not limited to, the following:

- Quality of Release
Uses acceleration at impact combined with shaft **34** lean at impact to determine the quality of the timing of the release.
- Tempo
This analytic scores the smoothness and rhythm of a golf swing. Smoothness will be determined by any rapid / unexpected accelerations and decelerations during a backswing and downswing. Rhythm will be determined by looking at the time during the backswing versus the time during the downswing.
- Divergence from Reference Swing (Quality of Swing)

Analysis application **88** allows for the comparison of a recorded golf swing to a reference swing. This reference swing can be, but is not limited to, a reference professional swing, a previously recorded user swing, or a swing recorded from another golfer. Analysis application **88** can tell the user where a given swing moves an unacceptable distance away from the reference swing.

[0071] Analysis application **88** provides for data transmission with other installations (not shown) of analysis application **88** over the internet or other communication medium. The ability to share swing path data **82** records allows for one user to record data regarding their swing and then transmit the data to a second user for further visualization and analysis. The second user can annotate swing path data **82** records with comments and then transmit the annotated files to their originator. The ability to transmit annotated data between users allows for remote instruction and feedback.

[0072] **FIGURE 11** shows an alternative embodiment **39** of RF link box of **FIGURES 2** and **8**. Like RF link box **38**, RF link box **39** includes a link board **70**, a link board transceiver chip **80**, USB circuitry (not shown), a USB connector **44**, a USB cable **46** (not shown), a link box cap **72**, a link box base **74**, a power/USB connection LED **42** and club detection data transfer LED **40**.

[0073] In addition, RF link box **39** includes a display screen **116** and a control panel **72**. Display screen provides portable access to analysis application **88** (**FIGURE 10**) as well

as providing information on IGC 18 and SGSAT configuration. The user manipulates analysis application 88 and configures IGC 18 and SGSAT via control panel 72.

[0074] In an alternative embodiment, computing device 48 may be incorporated into a wearable computer and a display may be incorporated into a pair of glasses so that a user can receive nearly instantaneous feedback during a game or practice. Currently, such computing devices and displays are available on the market.

[0075] **FIGURE 12** is a flowchart of a data collection process 200 associated with IGC 18 and SGSAT. Processing starts in a "Begin Operate IGC" step 201, which is initiated when a user presses power on/mute/power off button 20 (**FIGs. 1 and 4**) of IGC 18 (**FIGs. 1 and 4**). Prior to the initiation of process 200, IGC 18 is in an "Off" state, during which IGC 18 is in a very low power mode where all components are off and the central processing unit (CPU) clock is stopped. The CPU is configured to wake when the user presses power on/mute/power off button 20 or when battery recharger 32 (**FIGURE 3**) is inserted into battery recharger connector 28 (**FIGURE 1**).

[0076] From step 201, control proceeds immediately to an "Initialize SGSAT" step during which process 200 initializes the central processing unit (CPU), memory, buttons 20 and 26 and temperature sensor of IGC 18. In addition, process 200 initiates a beep from sounder 76 (**FIGURE 6**) so that the user can check sounder's 76 functionality and checks both battery pack 68 and the availability of an RF connection with RF link box 38 (**FIGs. 2 and 8**). If the RF connection is available,

indicating that RF link box 38 and computing device 48 are on-line, then LEDs 40 and 42 (FIGs. 2 and 8) are flashed so that the user has an indication of the condition of SGSAT. It should be noted that IGC 18 is able to operate and collect data without a RF connection available. Data transfer and processing can occur off-line at a more convenient time.

[0077] Following step 203, control proceeds to a "Wait For Input or Event" step 205 during which IGC 18 is in a "Doze" state. In this state, IGC 18 performs periodic checks for the presence of RF link box 38, to determine whether or not IGC 18 should transition to an "At Address" state and to determine if power on/mute/power off button 20 has been depressed for a period of four (4), indicating that the user wishes to return IGC 18 to the Off state. These periodic checks are illustrated by a transition of control by process 200 through a "Link Box Detected?" step 207, an "Address Detected?" step 211 and an "Off Signal Detected?" step 215. In Doze state and during the periods between At Address checks, most IMU 53 (FIGs. 4 and 6) devices are powered down in order to conserve power of battery pack 68.

[0078] In the absence of detected events, as indicated by the "No" paths of steps 207, 211 and 215, the transition through steps 207, 211 and 215 occurs every 100 ms. During step 207, IGC 18 powers up club transceiver chip 78 (FIGURE 6) to check for the presence of RF link box 38. If RF link box 38 is detected, then control proceeds to a "Process Link Box" step 209, which is described in more detail below in conjunction with FIGURE 13. Following step 209, control returns to step 205 and processing continues as described

above. In, in step 207 RF link box 38 is not detected, then control proceeds to "Address Detected?" step 211.

[0079] During step 211, process 200 takes acceleration readings from Cz and Cx axes (FIGURE 7) accelerometers (FIGURE 6), resolves the angle of the gravity vector, and reads an angular rate from the Cx axis gyroscope (FIGURE 6) to determine a lack of rotation. If IGC 18 determines that IGC 18 is being held in a upright manner consistent with the stance of a golfer prior to a swing and that IGC 18 is not being swung or moving around the Cx axis, IGC 18 moves from the Doze state into the At Address state and control proceeds to a "Process Swing" step 213, which is described in more detail below in conjunction with FIGURE 14. Following step 213, control returns to step 205 and processing continues as described above. If, in step 211, IGC 18 does not detect that the user is addressing the ball, then control proceeds to Off Signal Detected? step 215.

[0080] During step 215, IGC 18 determines whether or not power on/mute/power off button 20 has been pressed for a sustained period of time, e.g. four (4) seconds. If not, then control returns to 205 and processing continues as described above.

[0081] If power on/mute/power off button 20 has been pressed for a sustained period of time, then control proceeds to a "Power Down" step 217, during which IGC 18 takes actions necessary to return to the Off state in which, as described above, IGC 18 is in a very low power mode where all components are off and the central processing unit (CPU) clock is

stopped. Finally, control proceeds from step 217 to an "End Operate IGC" step 229 in which process 200 is complete.

[0082] It should be noted that, although process 200 is described here as a "polling" process, process 200 could also be engineered as an event or interrupt driven process. Those with skill in the computing arts should appreciate the both the advantages and disadvantages of the different approaches.

[0083] **FIGURE 13** is a flowchart of Process Link Box step 209 of Data Collection process 200 of **FIGURE 12** in more detail. As explained above, step 209 is entered when IGC 18 detects a request from the corresponding RF link box 38.

[0084] Step 209 starts in a "Begin Process Link Box" step 231 and proceeds immediately to a "Request for Data?" step 233 during which process 200 determines whether or not the signal from RF link box 38 is a data download request. If so, control proceeds to a "Download Data" step 235 during which IGC 18 enters a "RF Download" state and transmits stored swing path data 82 (**FIGURE 9**) to the computer application on computing system 48 (**FIGURE 2**) via RF link box 38, through the USB connector 44 (**FIGURE 2**), through the USB cable 46 (**FIGURE 2**), and finally to analysis application 88 (**FIGURE 10**). In an alternative embodiment, swing path data 82 is processed by the microprocessor of IGC 18 and data corresponding to the orientation and position of IGC 18, rather than the linear acceleration and angular rate of IGC 18, are transmitted from IGC 18 to RF link box 38.

[0085] Once data 82 has been downloaded, control proceeds to an "End Process Link Box" step 249 in which step 209 is complete. In addition, IGC 18 returns to the Doze state.

[0086] If process **200** determines in step **233** that the signal from RF link box **38** is not a data download request, then control proceeds to an "Upgrade Firmware?" step **237** during which process **200** determines whether or not the signal from RF link box **38** is a request to upgrade the flash memory and/or the memory of the microcontroller located on main board **52** (**FIGURE 6**) of IGC **18**. If so, control proceeds to a "Flash Memory" step **239** during which the firmware of IGC **18** is updated. Control then returns to End Process Link Box step **249** and processing continues as described above. Step **239** corresponds to a Flash Upgrade state of IGC **18**, which is entered only from an RF Download state.

[0087] Finally, if in step **237**, process **200** determines that the RF signal is not a RF update request, then control proceeds to step **249** and processing continues as described above.

[0088] **FIGURE 14** is a flowchart of Process Swing step **213** of Data Collection process **200** of **FIGURE 12** in more detail. Step **213** begins in a "Begin Process Swing" step **251** and control proceeds immediately to a "Wait for Motion" step **253** during which IGC **18** periodically samples all gyroscopes and accelerometers simultaneously every 0.0005 seconds, for a sampling rate of 2 kHz. At this point, IGC **18** is still in the At Address state.

[0089] After each sample, control proceeds to a "Sufficient Rotation" step **253** during which IGC **18** calculates the rotational rate of the club around the C_x axis and thereby determines whether or not IGC **18** has started swinging. If the rotation rate does not exceed the threshold, then control

proceeds to a "Timeout" step **257** during which IGC **18** determines whether or not IGC **18** has been at the At Address state for longer than a predetermined amount of time. If so, control proceeds to an "End Process Swing" step **269** in which step **213** is complete. If the predetermined period of time has not been exceeded, then control returns to step **251** and IGC **18** waits for another sample.

[0090] If, in step **255**, the rotation rate around the C_x exceeds the set threshold rate, IGC **18** enters a "Swinging" state and control proceeds to a "Sample Sensors" step **259**. During step **259**, IGC **18** samples all gyroscopes and accelerometers and stores the swing generated sensor data **82** to flash memory. As explained above in conjunction with **FIGURE 9**, swing data collected by IGC **18** is stored as swing path data **82** comprised of swing info header **84** with multiple swing data elements **86**. Swing info header **84** contains information such as initial timestamp, swing duration, swing flag status, and temperature. Each sampling IGC **18** sensors is stored in a swing data element file **86**. Each swing data element file **86** contains data regarding accelerations along C_x , C_y , and C_z axes and angular rate data around C_x , C_y , and C_z axes. Therefore, for a given swing, there exists a one-to-many relationship between swing info header **84** record and the multiple swing data element **86** records.

[0091] The described embodiment of the claimed subject matter employs a fixed sampling rate, i.e. 2 kHz. Therefore, given the initial timestamp and a fixed time between samples, a swing path can be chronologically recreated. IGC **18** also monitors its position with respect to the upper and lower

swing planes. While in the Swinging state, if club head **36** (**FIGURE 1**) breaks either the upper or lower swing planes, sounder **76** (**FIGURE 6**) produces an audible tone. This audible feedback can be toggled between a sound on and a sound off, or mute, configuration by briefly depressing power on/mute/power off button **20**.

[0092] After each sampling interval, control proceeds from step **259** to a "Time Exceeded?" step **261** during which process **200** determines whether more time has elapsed than necessary to complete a swing of IGC **18**. If so, control proceeds to a "Write Data" step **265** during which the data samples captured during iteration through step **259** are copied to and stored in a memory. IGC **18** then returns to a Doze state and control proceeds to an "End Process Swing" step **269** in which step **213** is complete.

[0093] If, in step **261**, process **200** determines that the swing has not exceeded the maximum allowable time, then control proceeds to an "Insufficient Rotation?" step **263** during which process **200** determines whether or not IGC **18** is moving sufficiently fast to still be considered in the process of a swing. IGC **18** determines the end of the swing by monitoring the moving average of rotation vector magnitude. The magnitude of the rotation vector is calculated by taking the square root of the sum of the squared values of angular rate around the C_x , C_y , and C_z axes. If the moving average falls below a set threshold the swing is declared complete and control proceeds to Write Data step **265** and processing continues as described above. If, in step **263**, process **200** determines the swing is still active, i.e. the moving average

is above the threshold, then control returns to step 259 and more data samples are collected as described above.

[0094] **FIGURE 15** is a flowchart of a data display process 300 associated with IGC 18 and the SGSAT. Process 300 starts in a "Begin Display Data" step 301 that is initiated when computing device 48 (**FIGURE 2**) is turned on and analysis application 88 (**FIGURE 10**) is launched. Power from computing device 48 is employed to power RF link box 38 (**FIGURE 2**) via USB cable 46 (**FIGURE 2**). Control proceeds to an "Update Data" step 303 during which a user is provided an interface (not shown) for adding, editing and/or updating a user profile. If necessary, the user profile is also reconciled, or "synced," with data from IGC 18 (**FIGURE 1** and **4**).

[0095] Following updating of the user profile in step 303, if performed, control proceeds to a "Application Patch Required?" step 305 during which process 300 determines whether or not a later version of analysis application 88 is available for download. If an application patch is available, control proceeds to a "Download Application Patch" step 307 during which the corresponding patch is downloaded and applied to analysis application 88. Those with skill in the computing arts should know of different methods of notifying an application that an upgrade is available and of applying the patch to analysis application 88.

[0096] If an application patch is either unavailable in step 305 or downloaded and applied in step 307, control proceeds to a "Firmware (FW) Patch Available?" step 309 during which process 300 determines whether or not a later version of process 200 (**FIGS. 12-14**), or IGC 18 firmware, is available

for download. If a firmware patch is available, control proceeds to a "Download FW Patch" step **311** during which the corresponding patch is downloaded and applied to the flash memory of IGC **18**. Step **311** on computing device **48** corresponds to Upgrade Firmware step **237** and Flash Memory step **239** explained above in conjunction with **FIGURE 13**. In other words, if a firmware patch is available in step **309**, then events are triggered on computing device **48** that cause IGC **18** to execute steps **237** and **239**.

[0097] If a firmware patch is either unavailable in step **309** or downloaded and applied in step **311**, control proceeds to a "Collect IGC Data" step **313** during which analysis application **88** signals IGC **18** via RF link box **38** and collects any data collected by IGC **18**. Step **313** corresponds to Request For Data? step **233** and Download Data step **235** of process **200**. In other words, step **313**, executed on computing device **48**, causes IGC **18** to execute steps **237** and **239**.

[0098] From step **313**, control proceeds to a "Share Swing Data? step **315** during which process **300** determines whether or not there is a signal to export user profile and/or swing data to another application. If such a signal is present, then control proceeds to an "Export Swing Data" step **317** during which user profile and/or swing data is transmitted to another SGSAT application. As explained above in conjunction with **FIGURE 10**, SGSAT provides for data transmission with other instantiations of SGSAT. The ability to share swing path data allows one user to record data regarding their swing and then transmit the data to a second user for further visualization and analysis. The second user can annotate swing path data

with comments and then transmit the annotated files to their originator. The ability to transmit annotated data between users allows for remote instruction and feedback.

[0099] If there is either no signal to export in step **315** or data is exported in step **317**, control proceeds to a "Display Data" step **319** during which process **300** via analysis application **88** provides the user with visual feedback. Two examples of visual feedback include, but are not limited to, swing analytics and swing visualization. Swing analytics includes such information as the quality of impact with a golf ball, the corresponding geometric planes of the swing, a projected distance, the consistency among multiple swings and other advanced analytics. Swing visualization includes such information as multiple views of a particular swing, replay of a swing at various speeds and the viewing of specific segments of a swing.

[00100] Finally, control proceeds to an "End Display Data" step **339** in which process **300** is complete.

[00101] All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[00102] The use of the terms "a" and "an" and "the" and similar referents in the context of describing embodiments of the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly

contradicted by context. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate embodiments of the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[00103] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any

combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

[00104]